A Climate Model Prediction Perspective

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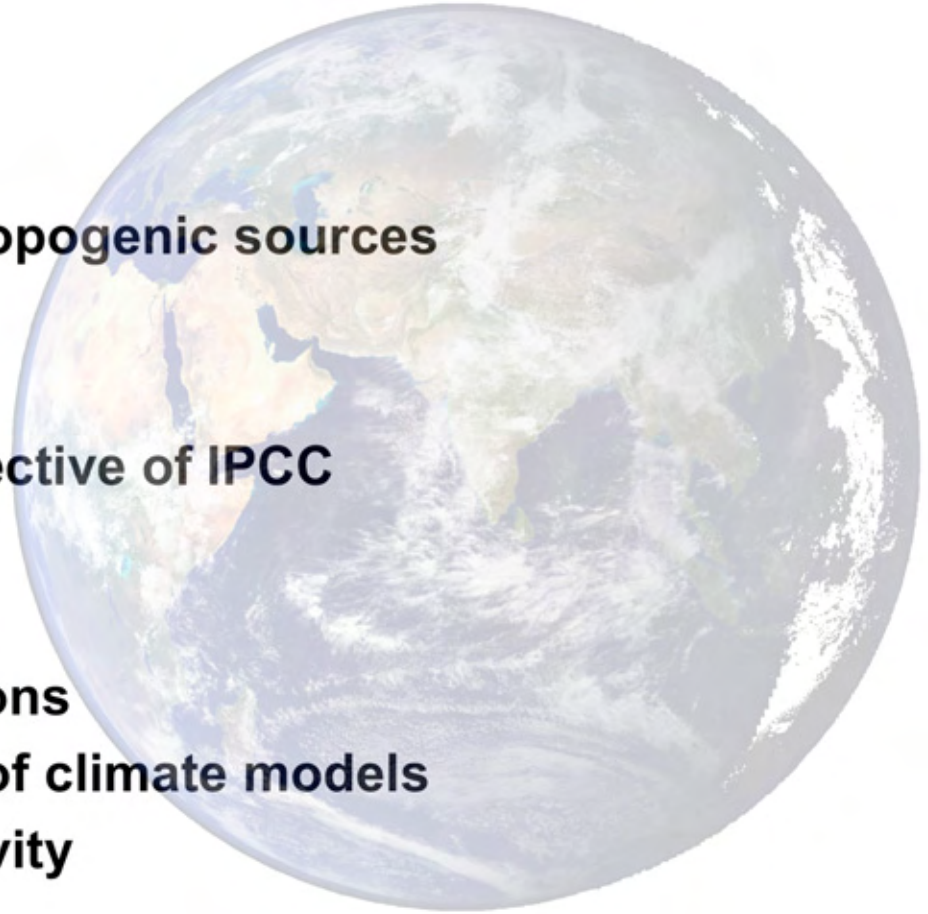
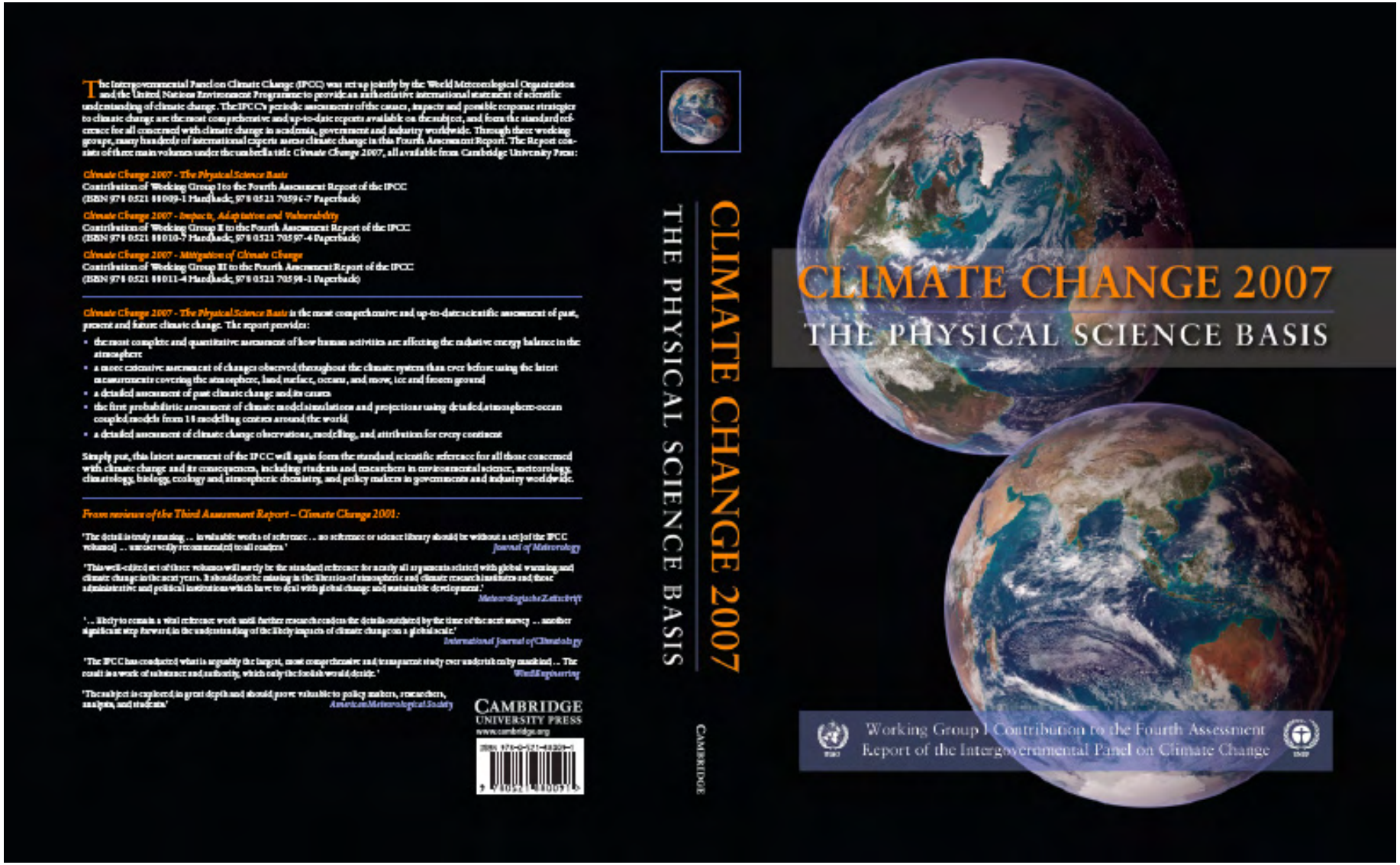
Role of CLARREO: A modeler's view

- **Key issues for climate change:**
  - **Detection of climate change**
  - **Attribution to natural or anthropogenic sources**
  - **Forecasts of future change**
- **State of these issues from perspective of IPCC**
- **Central questions for models:**
  - **Veracity of near-term predictions**
  - **Evaluation and improvement of climate models**
  - **Distribution of climate sensitivity**

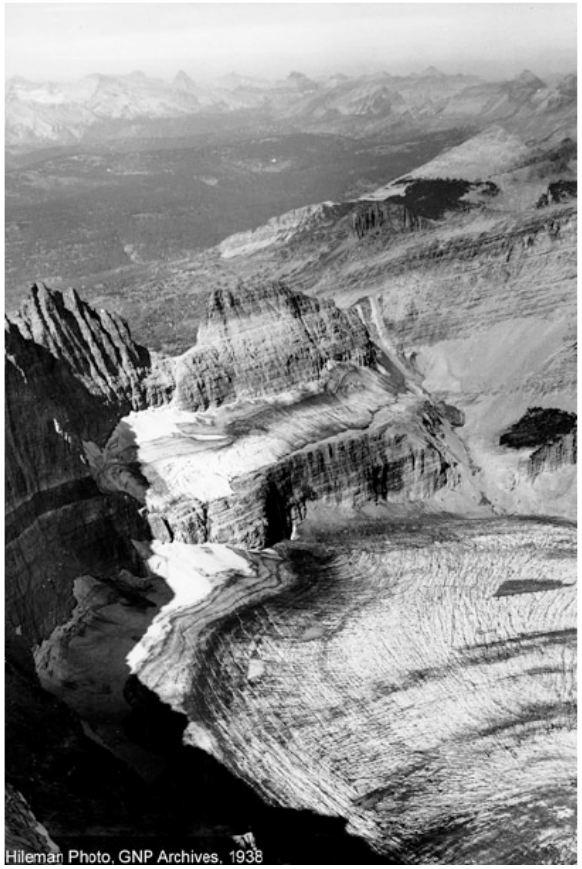


Key findings from IPCC WG1



Evidence for physical climate change

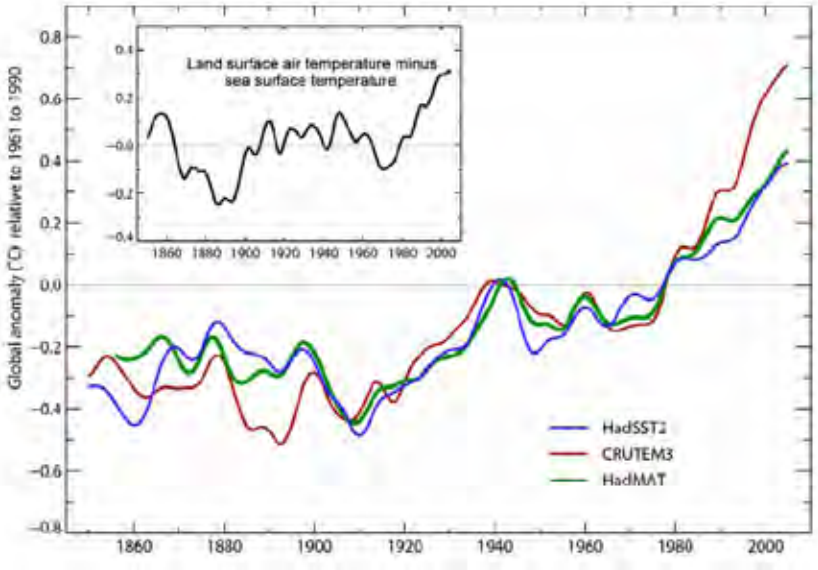
Grinnell Glacier, Montana, 1938



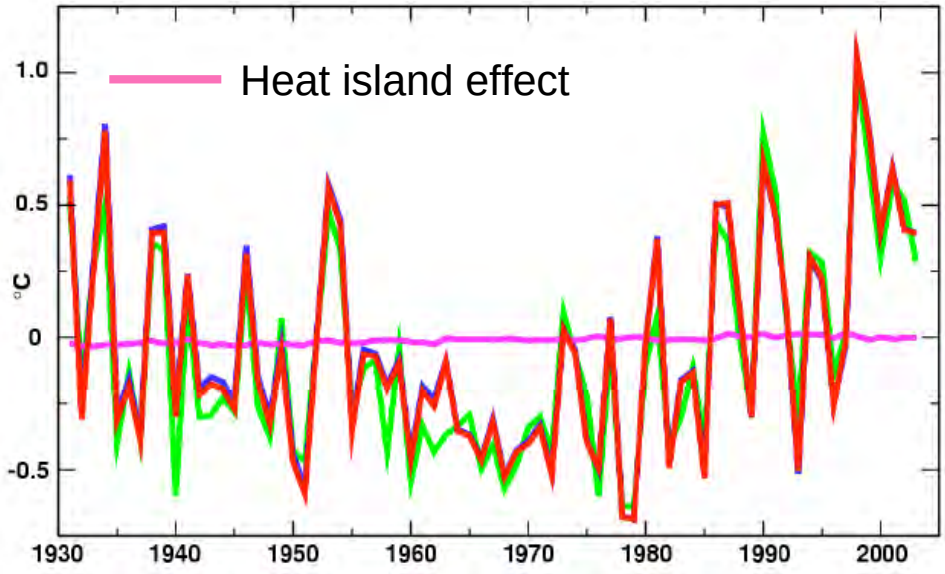
Grinnell Glacier, Montana, 2005

Increasing global temperatures

Global Temperatures



Urban Heat Island Effect

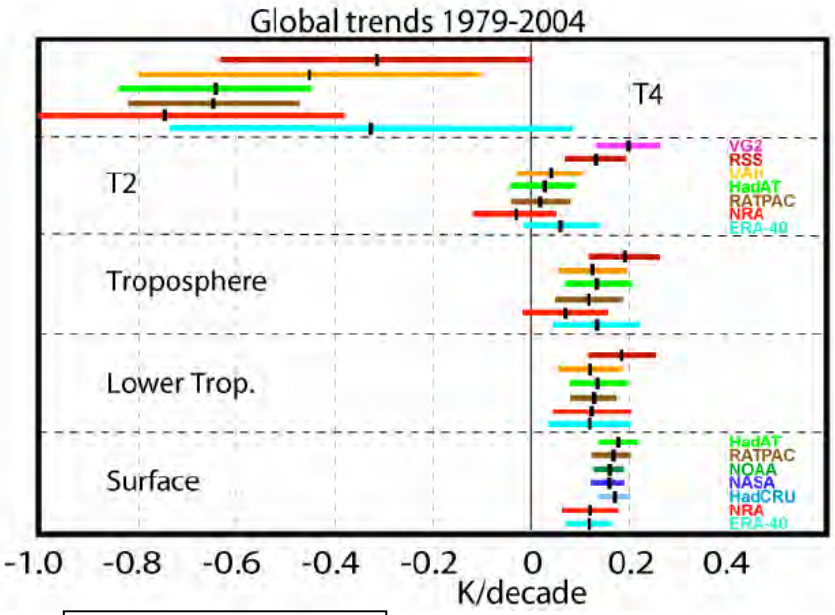


IPCC AR4, 2007

- Earth has warmed by 0.76 ± 0.19K since 1850.
- Measurement artifacts do not affect global trends.

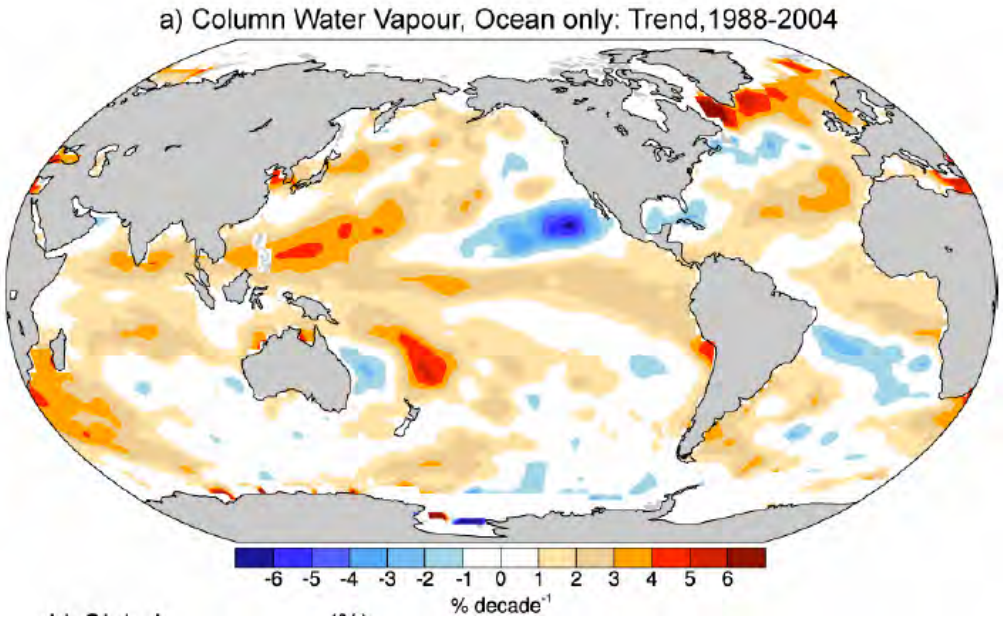
Atmospheric temperature and moisture

Air Temperature Trends



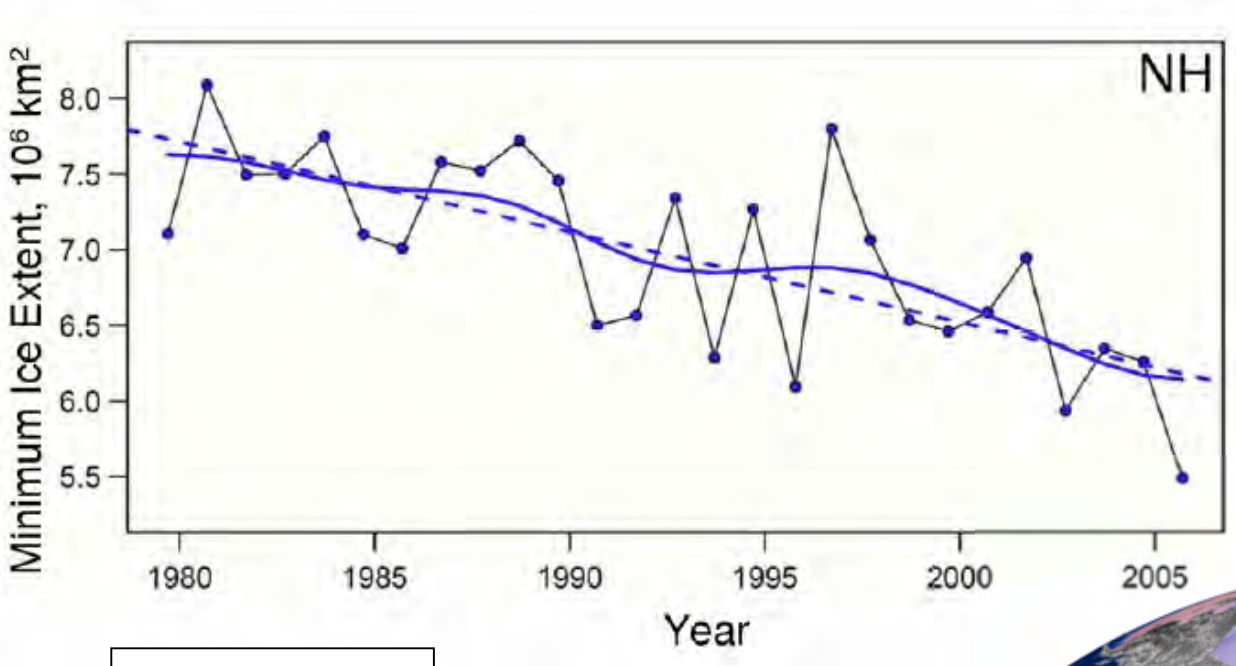
IPCC AR4, 2007

Atmospheric Moisture Trends



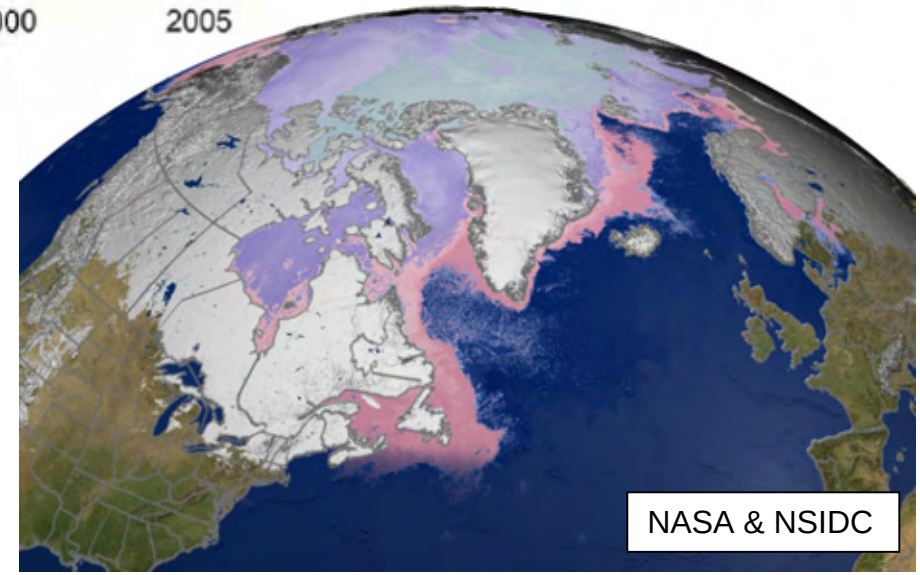
- Troposphere is warming by 0.16K to 0.18K per decade.
- Tropospheric humidity is increasing by 1.2%/decade.

Reductions in Arctic sea ice



IPCC AR4, 2007

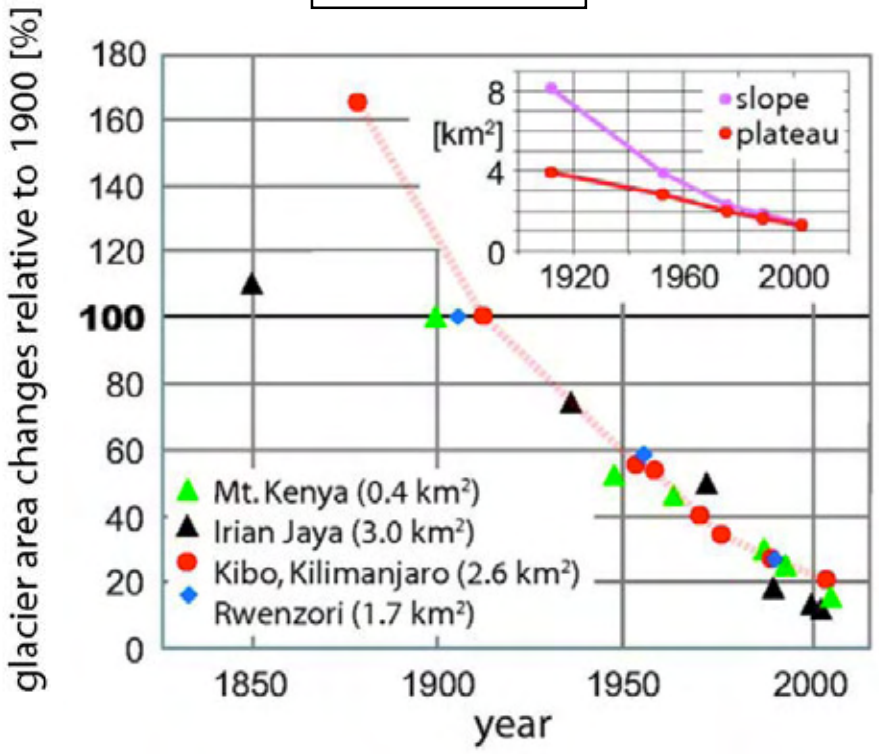
- Arctic summer sea ice extent is shrinking at 7.4±2.4% per decade.



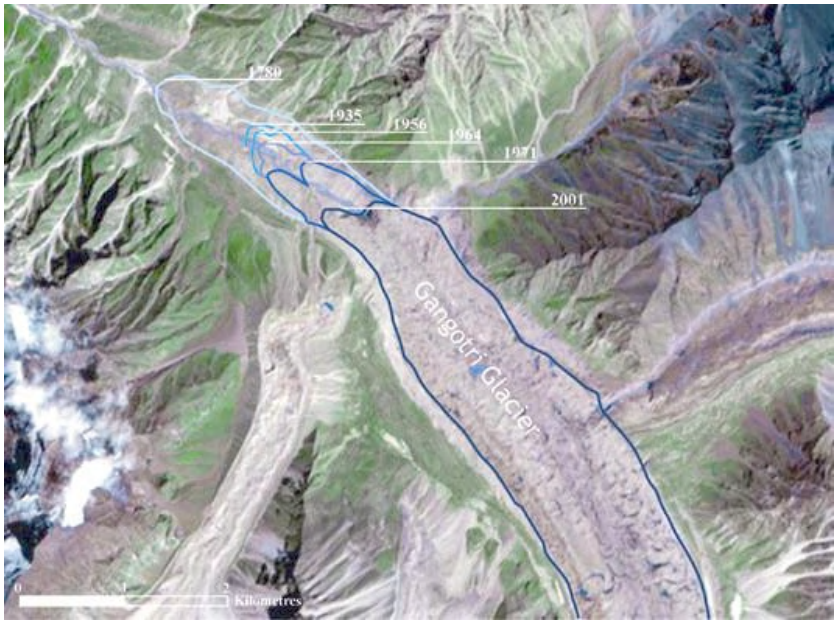
NASA & NSIDC

Trends in land glaciers and ice

Glacial Area

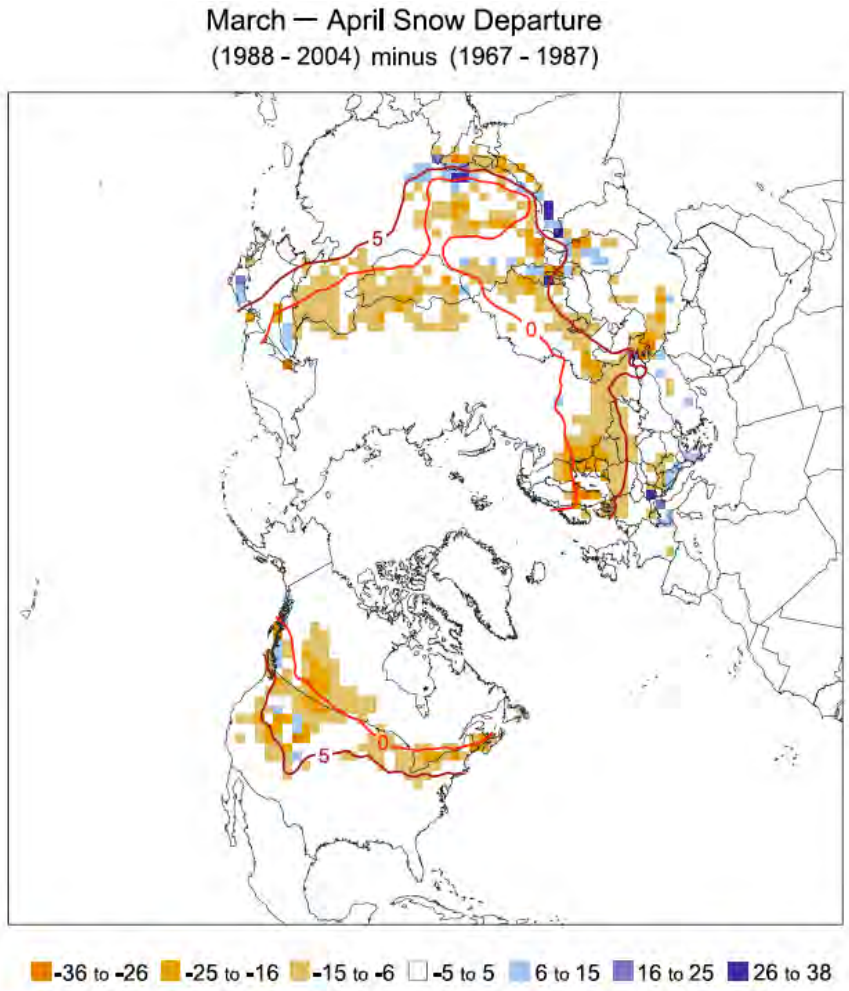


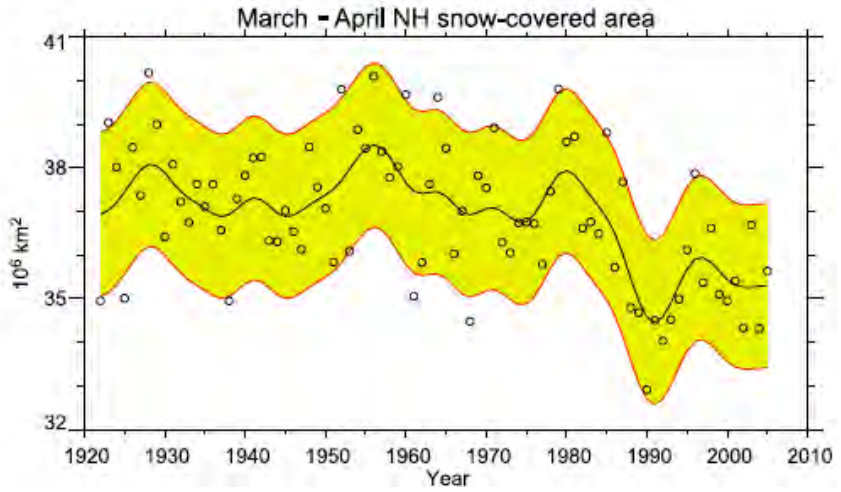
Gangotri Glacier, Northern India



- Mass loss from glaciers since 1991 is 0.77±0.22 mm/year SLE.
- This accounts for approximately 1/4 of the observed sea-level rise.

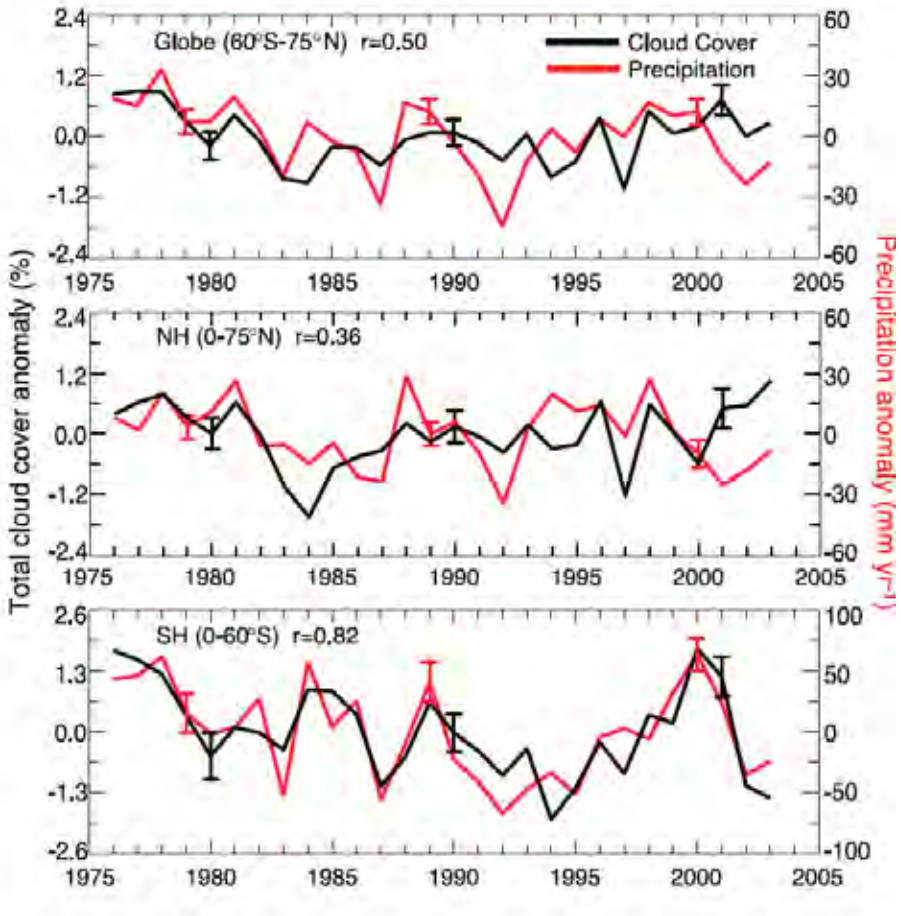
Trends in N. hemisphere snow cover





- Since 1988, snow cover has declined by 5%.
- Linear trend is -0.9±0.4% per decade.

Trends in global and regional cloud



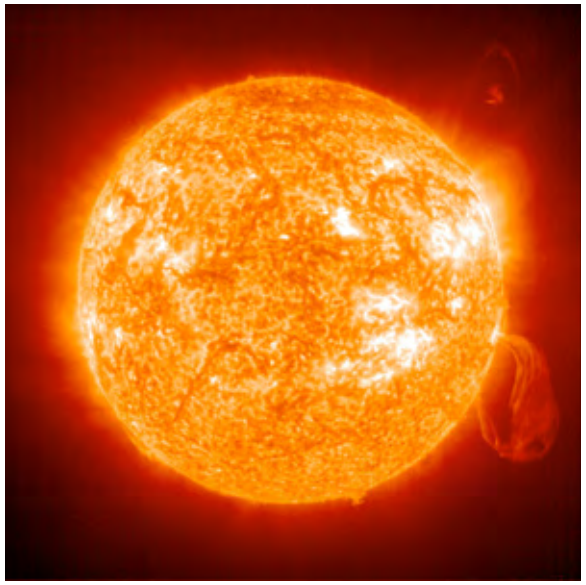
- Evidence generally supports reduction in high cloud amounts from 1980s to 1990s.
- There are substantial uncertainties in magnitude (and sign) in decadal trends.

CLARREO and climate-change detection

- **Accurate decadal-length records are essential for detection.**
- **Temperature and humidity will continue to be key fields.**
- **Detection of long-term changes in temperature gradients is important for atmospheric dynamics and regional climate.**
- **Reduction in land and sea-ice, frozen soil, and snow are manifest -- impacts on planetary albedo and feedbacks?**
- **Trends in low and mid-level cloudiness are very uncertain.**
- **Is the recent reduction in high-level cloudiness supported by other data, and does it represent a long-term trend?**

Attribution of recent climate changes

Volcanic eruptions

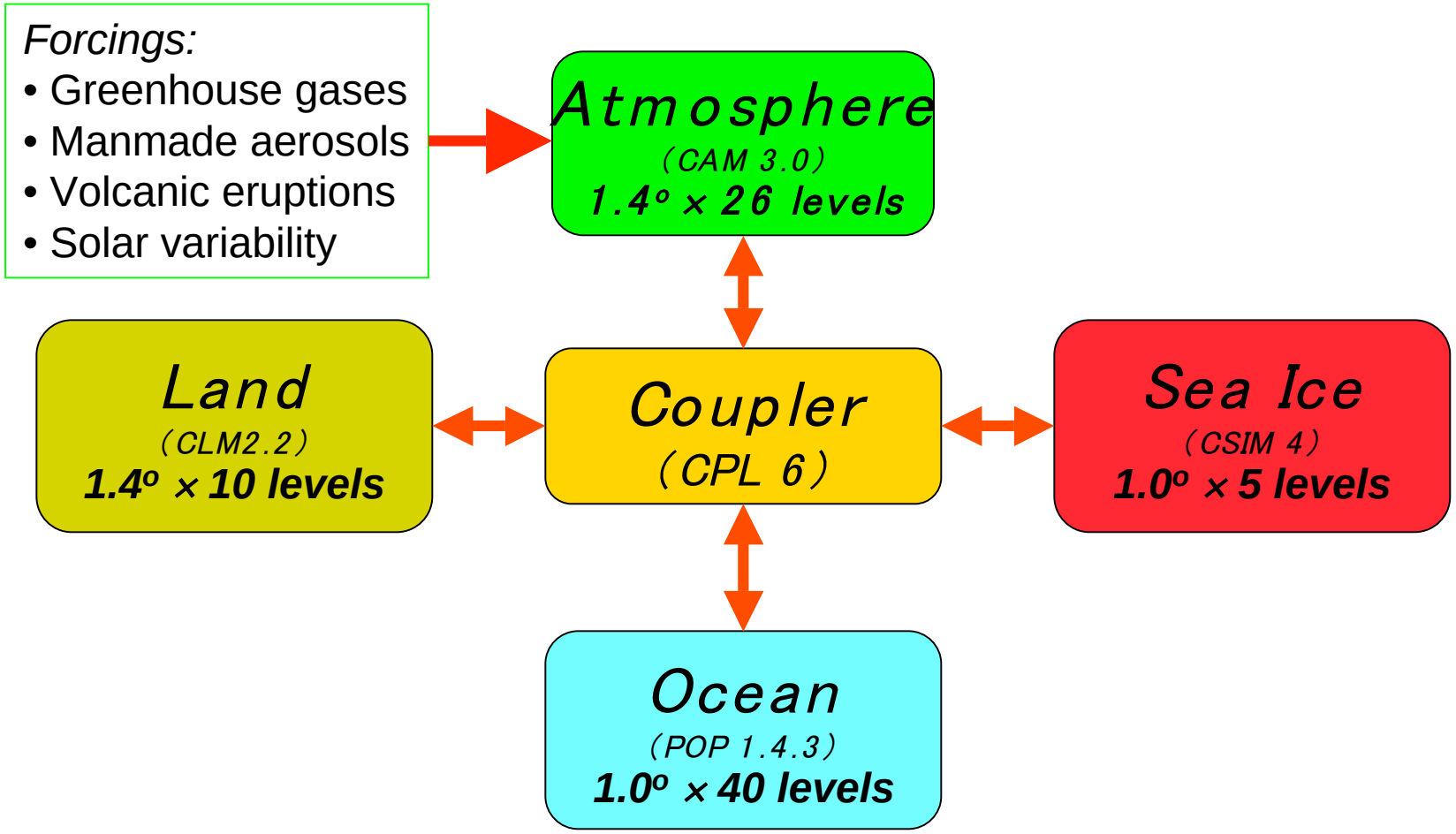


Solar variability

Human Pollution

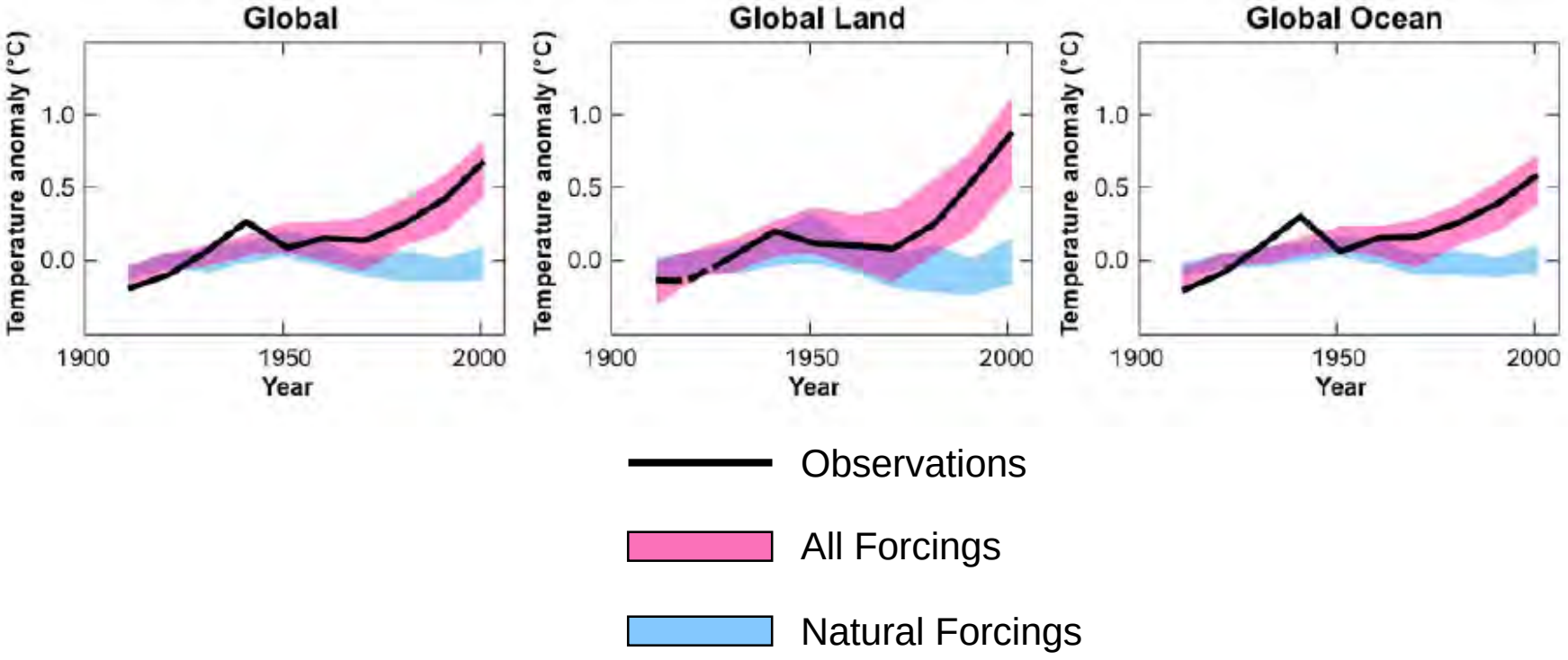
- Attribution has and will continue to be based primarily on:
  - Temperature
  - Ocean heat content
- Atmospheric moisture can now be used for attribution as well.

Method for attribution: Climate models



CCSM3 Model: http://www.ccsm.ucar.edu

Attribution of past climate change

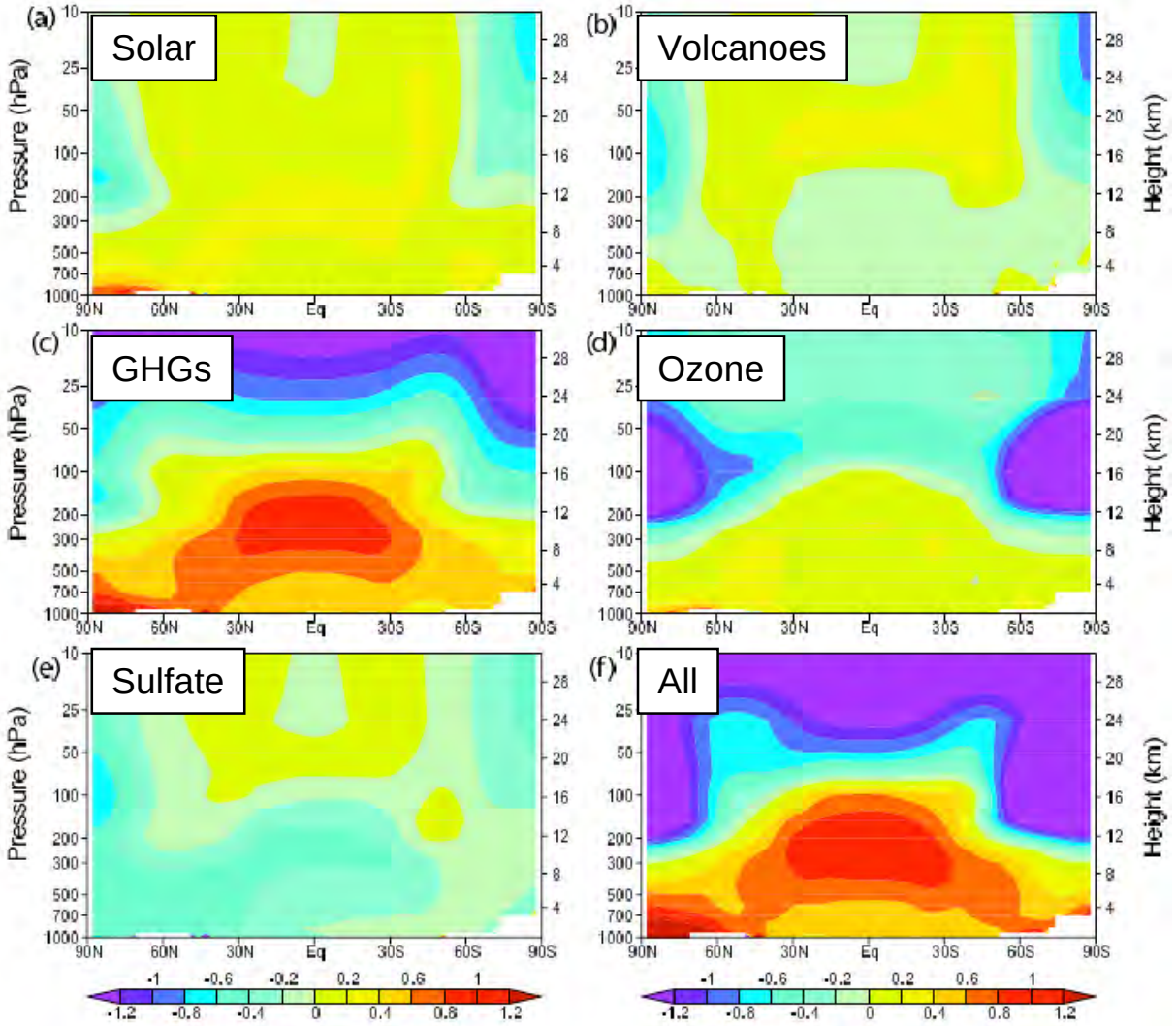


- Models with only natural forcings do not match observations.
- It is very likely (>90%) humans are cause of recent warming.

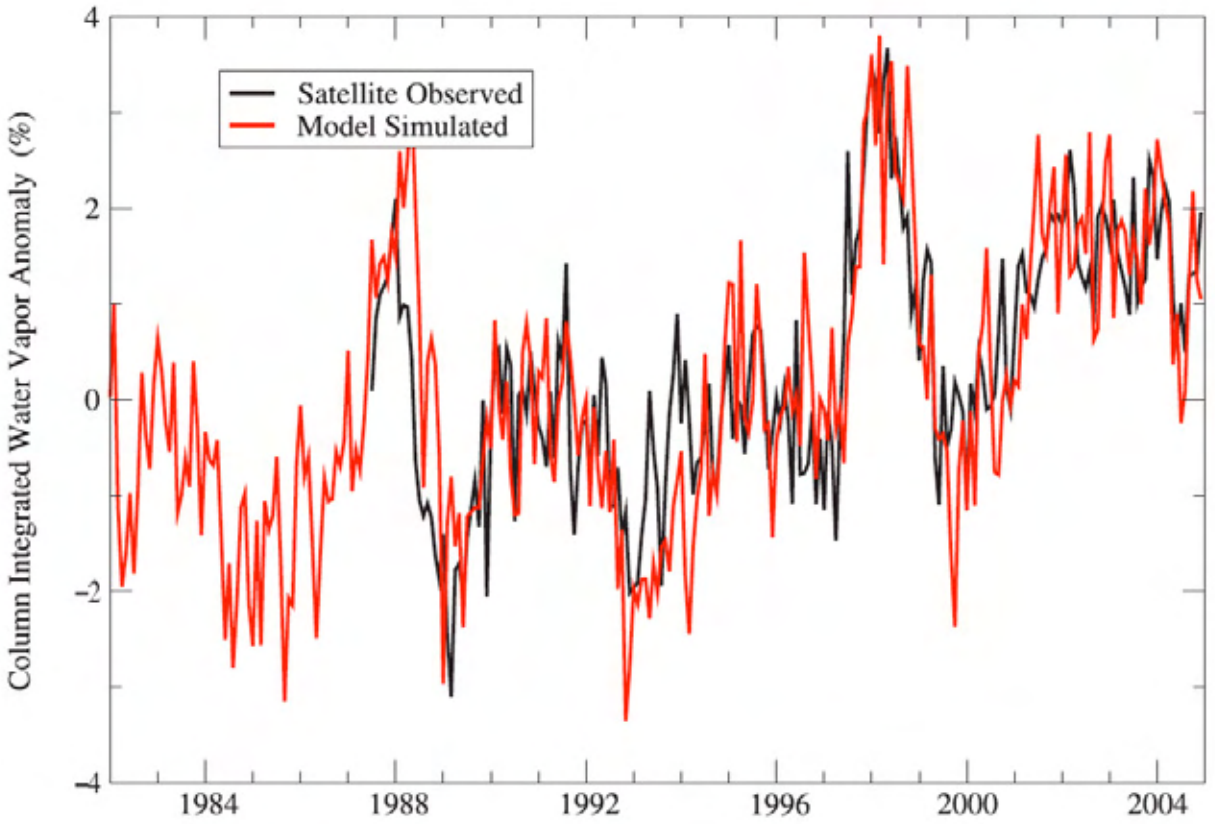
IPCC AR4, 2007

Attribution with optimal fingerprinting

Zonal mean atmospheric temperature change from 1890 to 1999 (°C/Century)

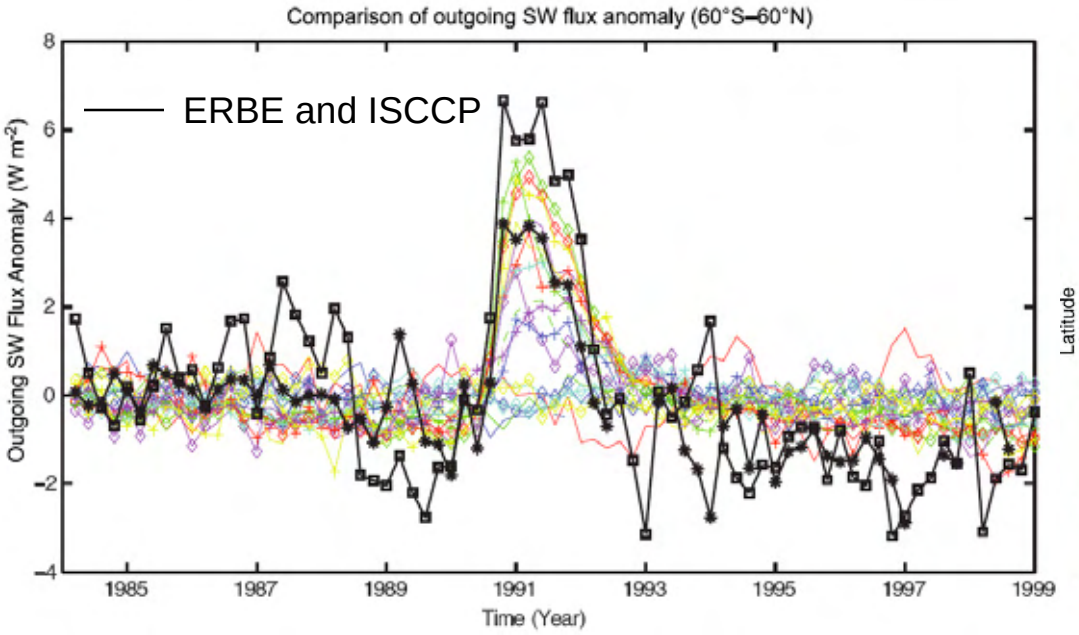


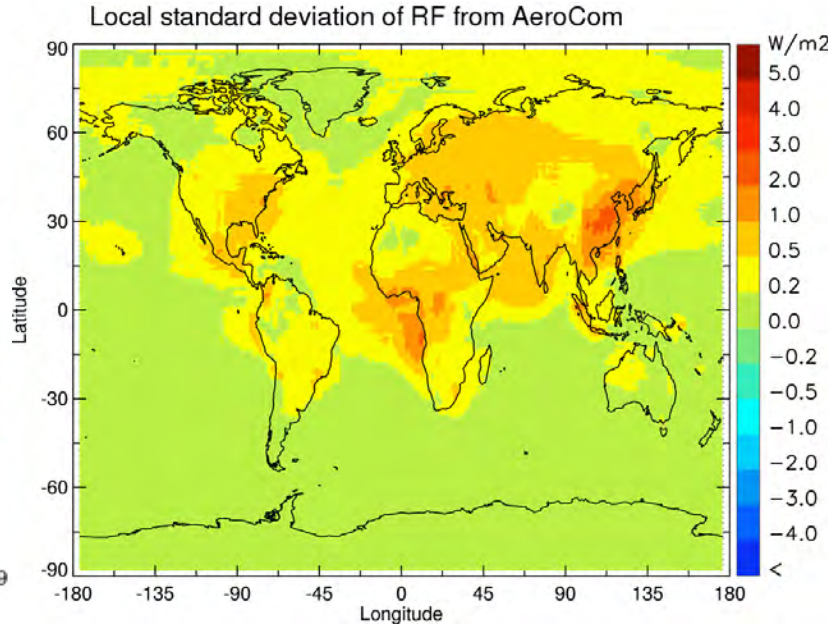
Changes in atmospheric humidity



- Models forced with observed SSTs reproduce 1.2%/decade trend.
- Fingerprinting shows human forcing is primary cause (Santer, 2007).

Principal uncertainties in attribution



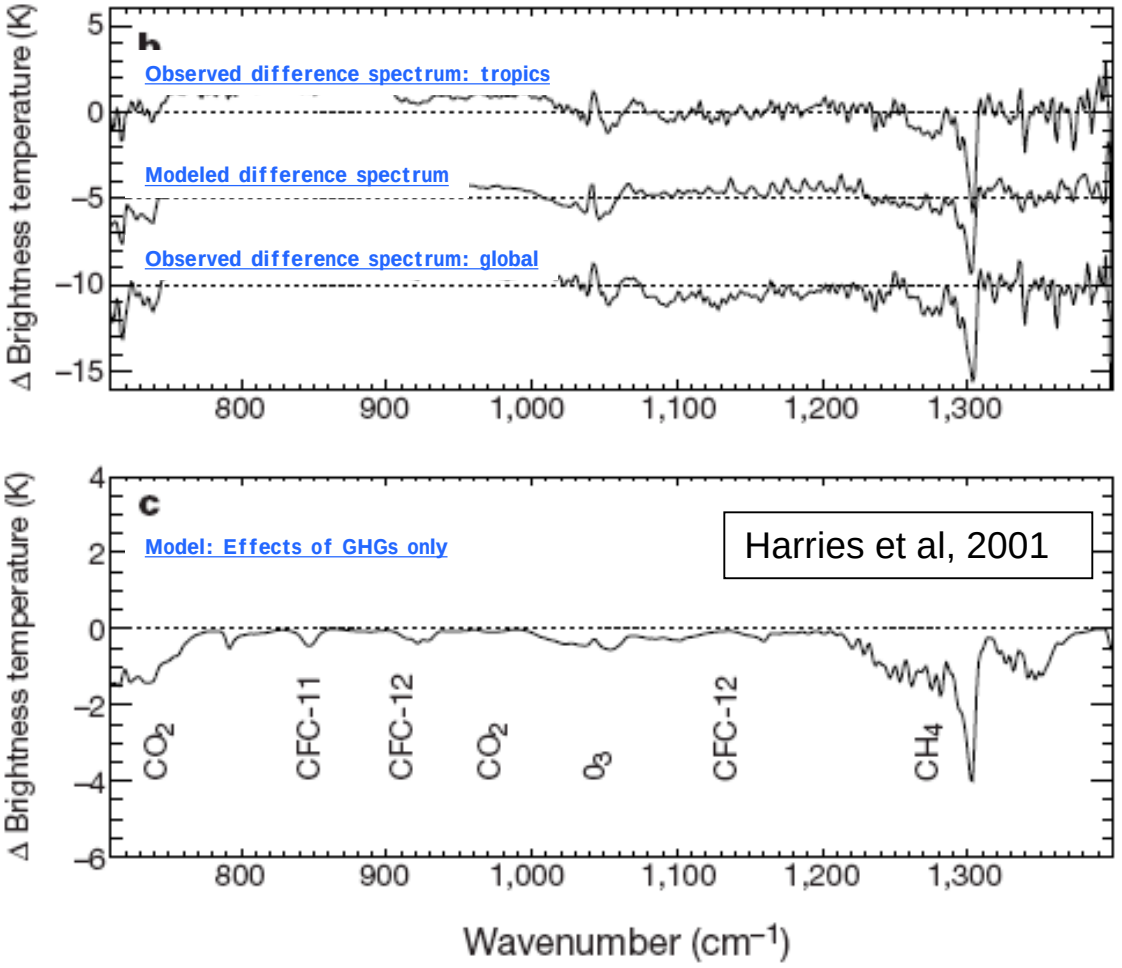


- Aerosol forcing remains quite uncertain, both in models and data.
- Forcing for 20th C. from inverse methods ranges from -1.7 to -0.1 Wm^{-2}.

Effects of GHG Increases over 1970-1997:

Direct evidence of anthropogenic forcing

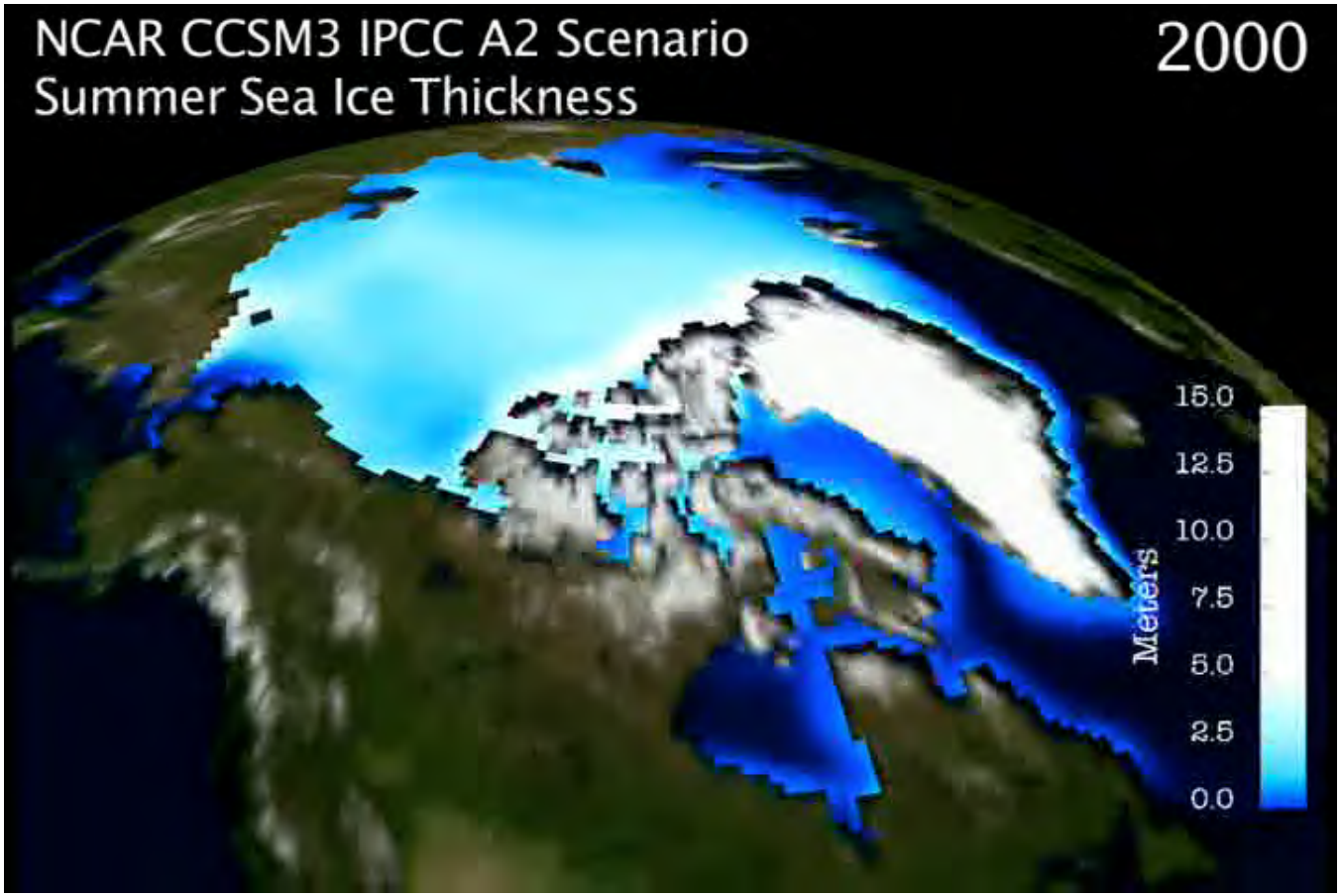
Differences between TES and IRIS in mid-infrared Wavelengths



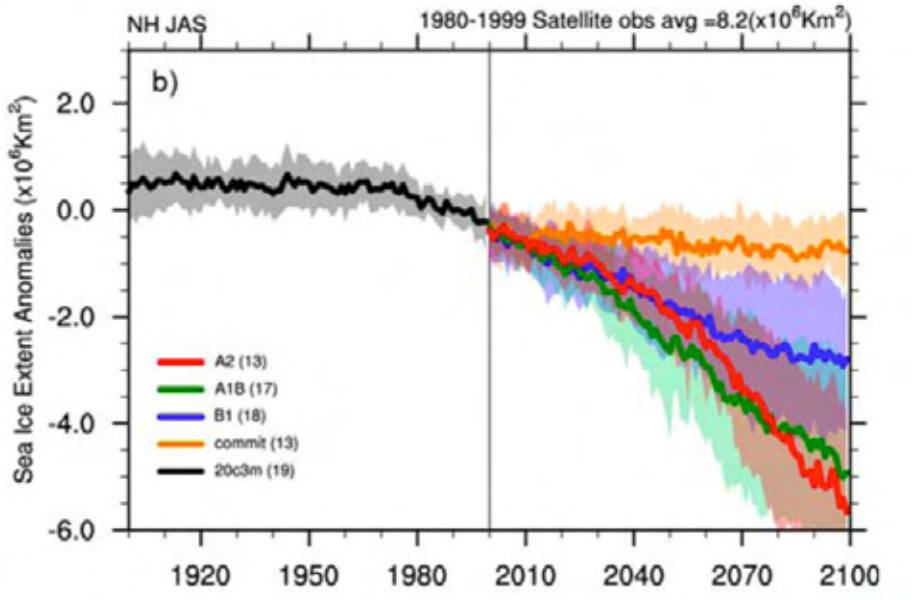
CLARREO and climate-change attribution

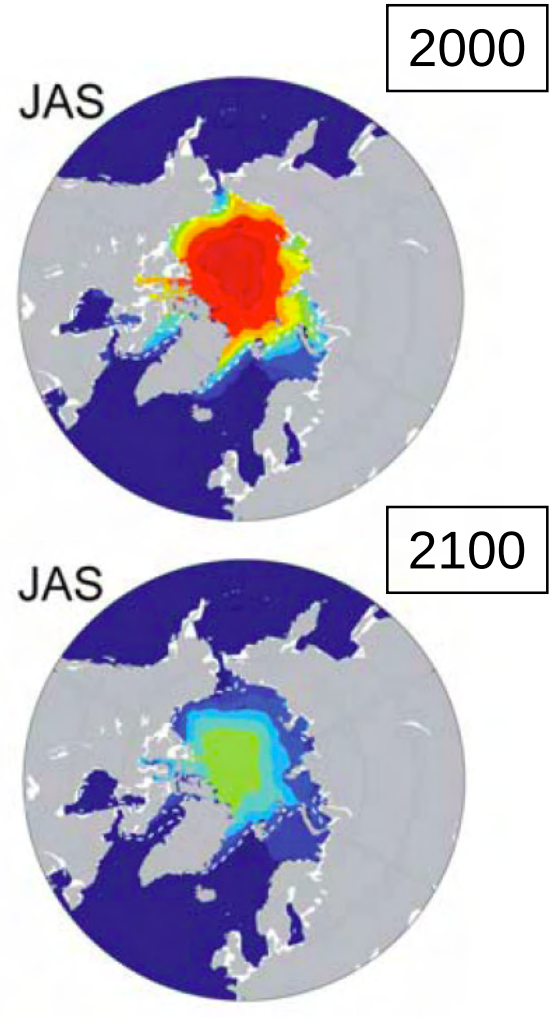
- **Accurate decadal-length records are essential for attribution.**
- **Temperature and humidity will continue to be key fields.**
- **Detection of long-term changes in temperature gradients is vital for fingerprinting studies.**
- **Models exhibit large variations in albedo and albedo trends.**
- **Long-term measurements of albedo require cross-calibration.**
- **It is critical to monitor the Earth's infrared spectrum for:**
  - **Effects of long and short-lived greenhouse gases**
  - **Evidence for natural forcing trends, in particular dust**

Future evolution of the Earth's climate



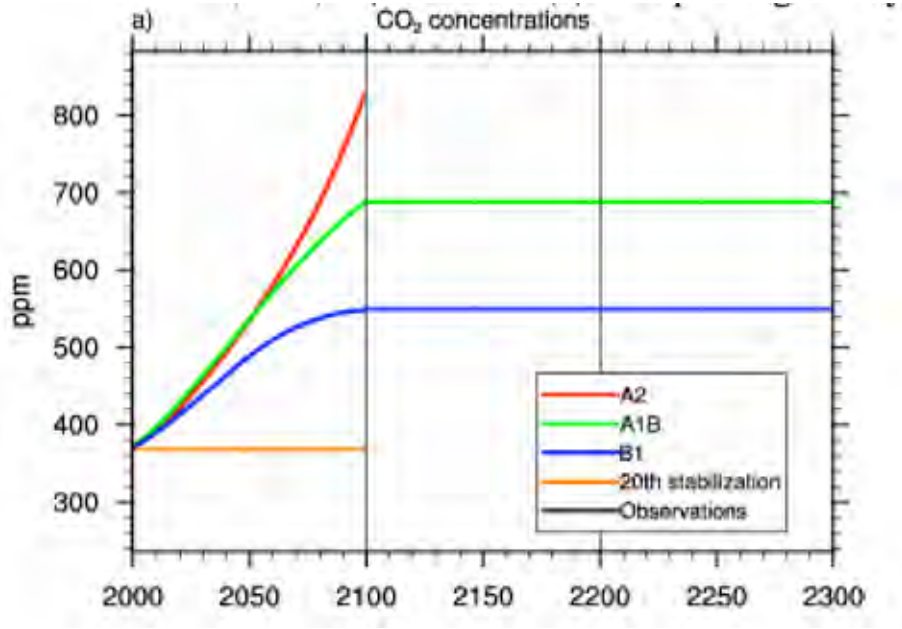
Further reductions in Arctic sea ice



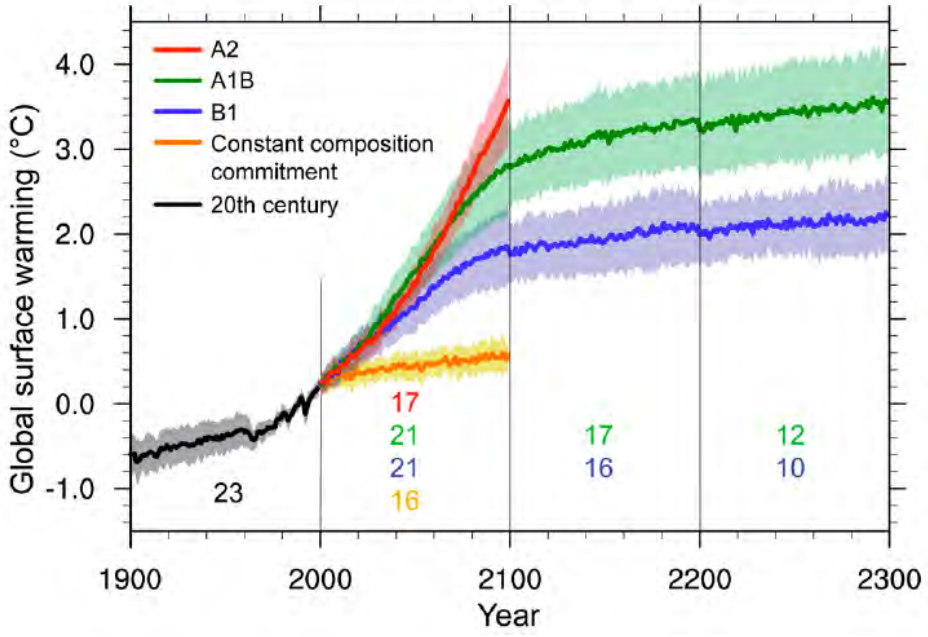


Projections for global temperatures

Emissions Scenarios

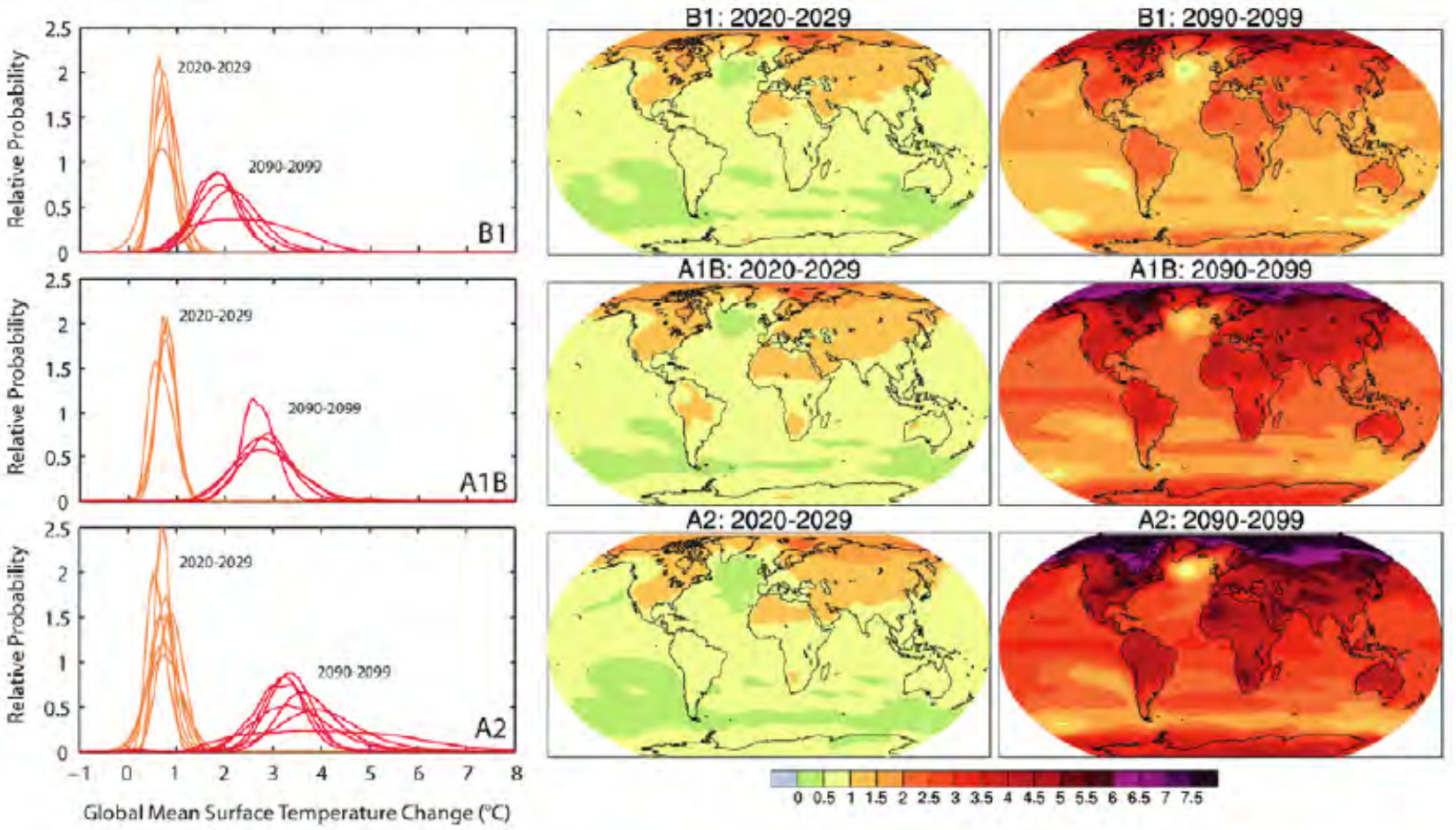


Global Temperature Projections



• Global temperatures could increase by 1.7 to 3.2K.

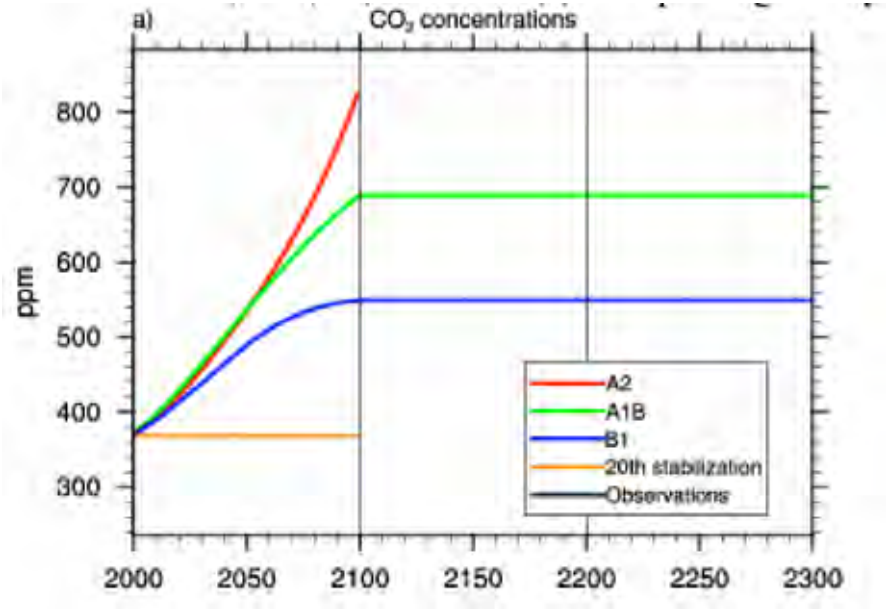
Projection of regional temperatures

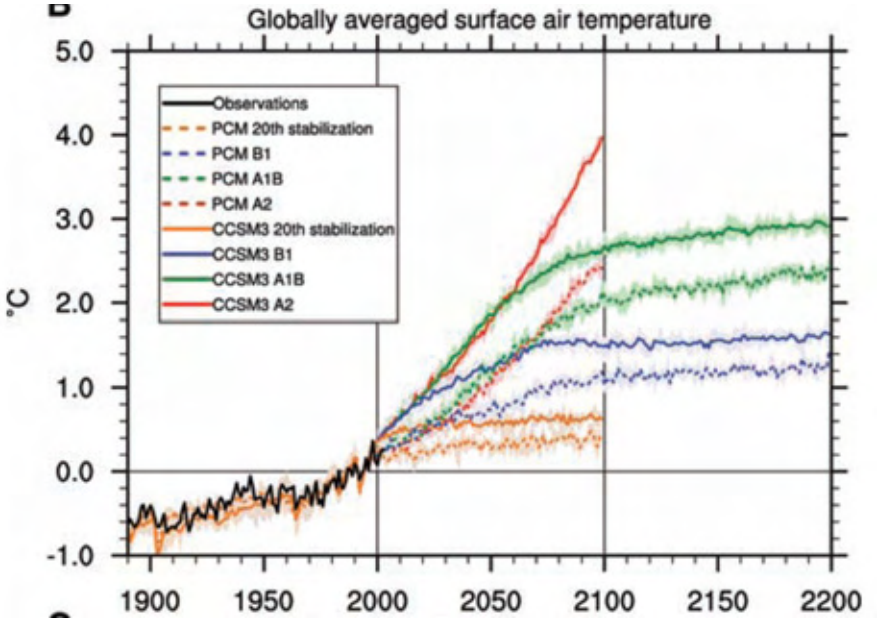


IPCC AR4, 2007

- Roughly 2/3 of warming by 2030 is from historical changes.
- Warming by 2030 exceeds 20th C natural variability by >2x.

Decadal projections of temperature





Meehl et al, 2005

- Between 50 to 70% of warming in 2050 relative to pre-industrial periods Is “committed”.
- Therefore the short-range predictions are relatively insensitive to socioeconomic scenarios.

Transient Climate Response and Equilibrated Climate Sensitivity

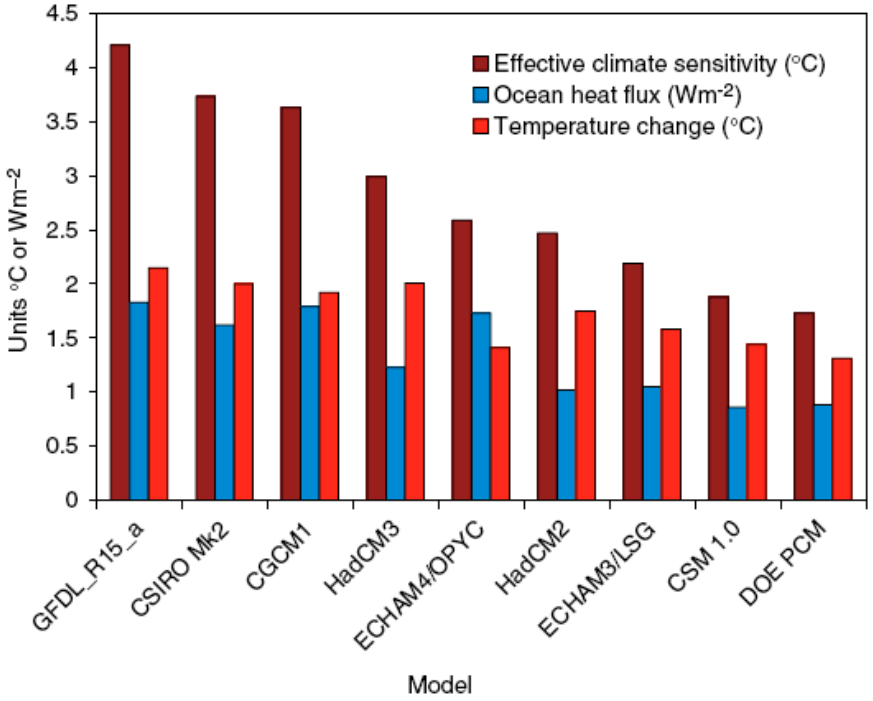
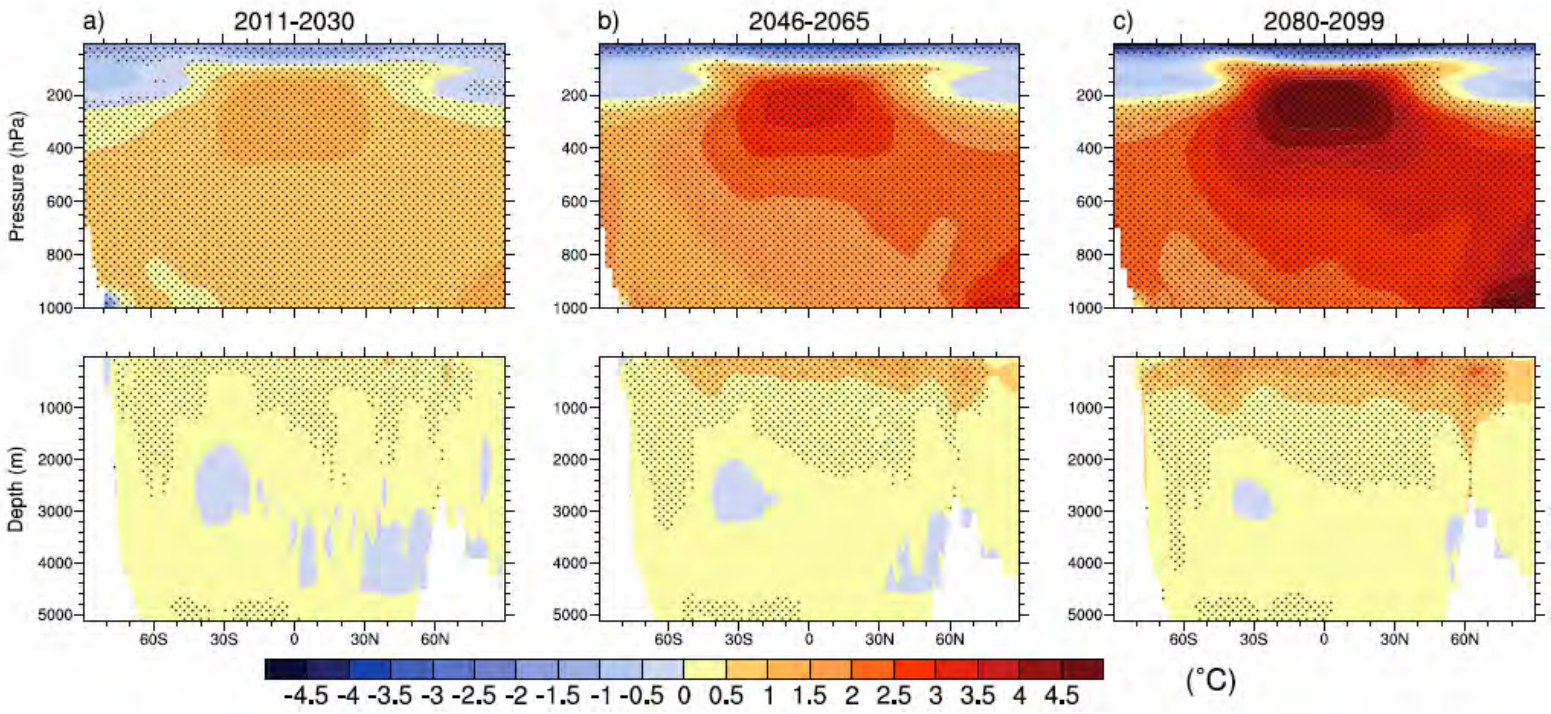


Figure 9.20: Comparison of CMIP2 model results for 20-year average values centred on year 70, the time of CO_2 doubling. Values are shown for the effective climate sensitivity, the net heat flux across the ocean surface multiplied by the ocean fraction and the global mean temperature change (TCR).

IPCC TAR, 2001

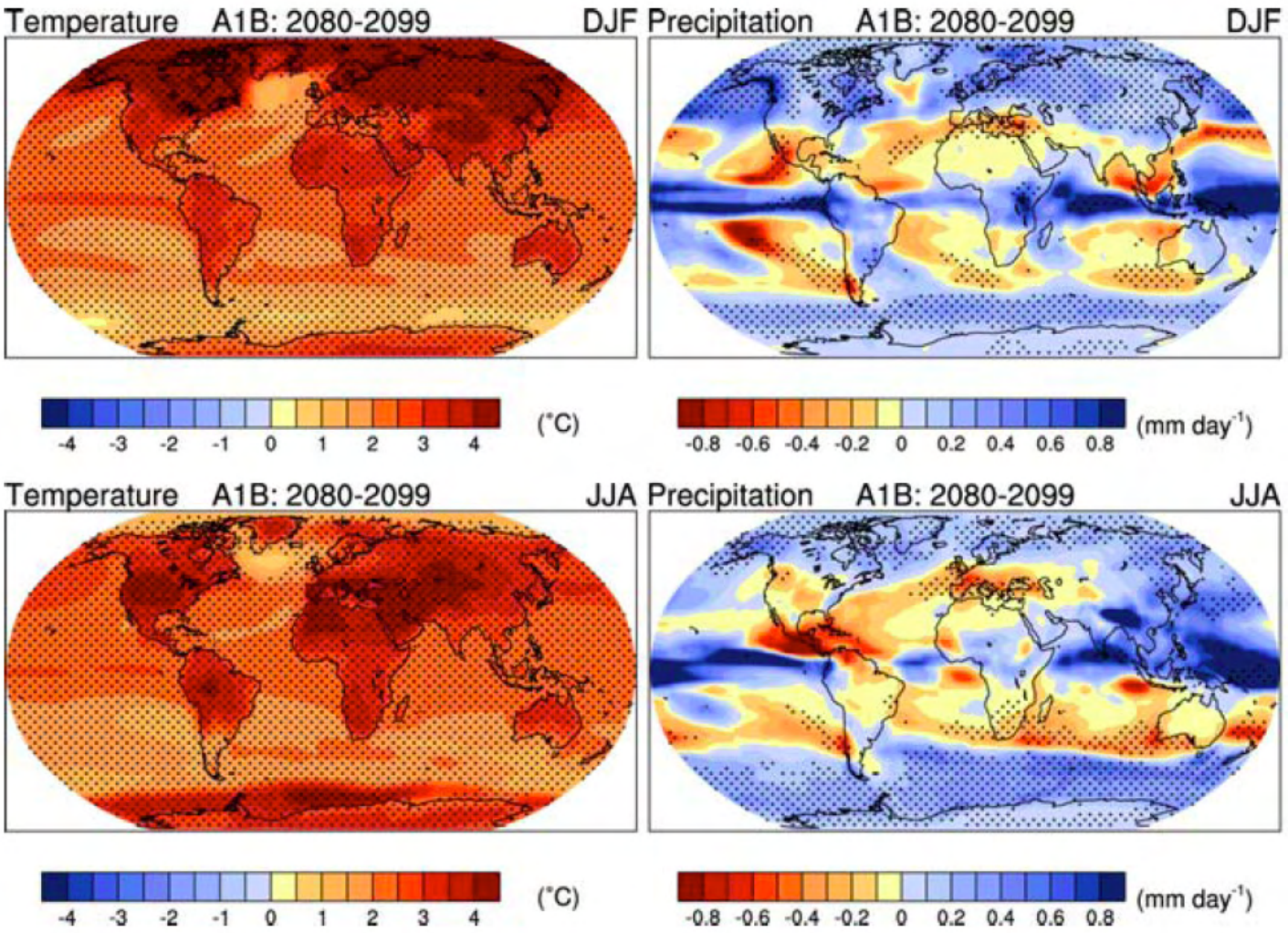
- The range of transient response is 3X smaller than the equilibrated sensitivity.
- Therefore the multi-model set of short-term predictions should be more consistent.

Atmospheric temperature changes



- Increases in tropospheric temperatures are manifest by 2030.
- Warming by 2030 exceeds multi-model variability by at least 1σ.

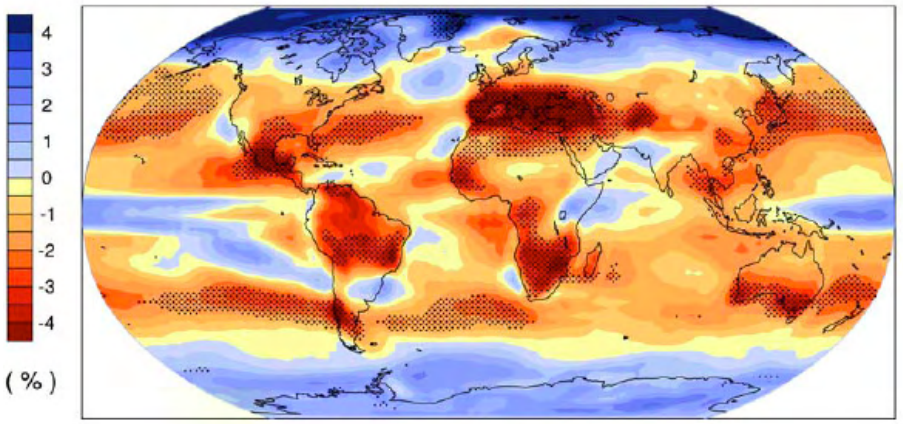
Low confidence in impact on rainfall

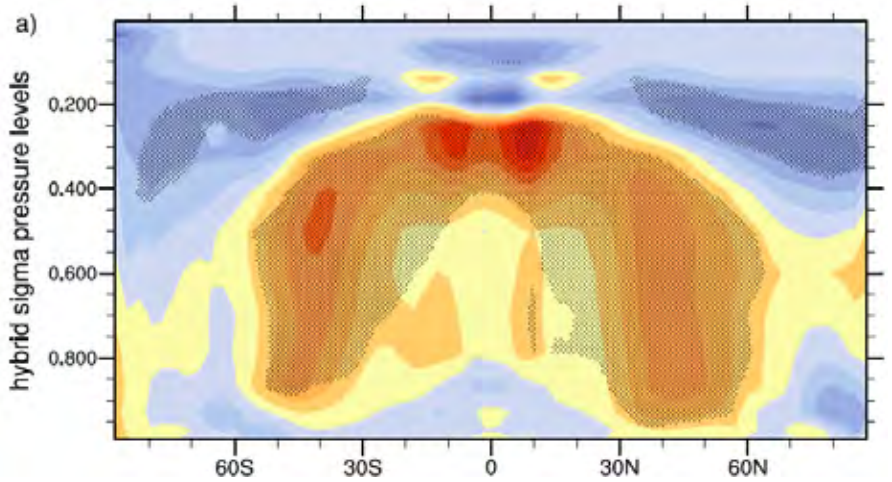


IPCC AR4, 2007

Low confidence in cloud evolution

Change in cloud amount in 21st century: A1B Scenario



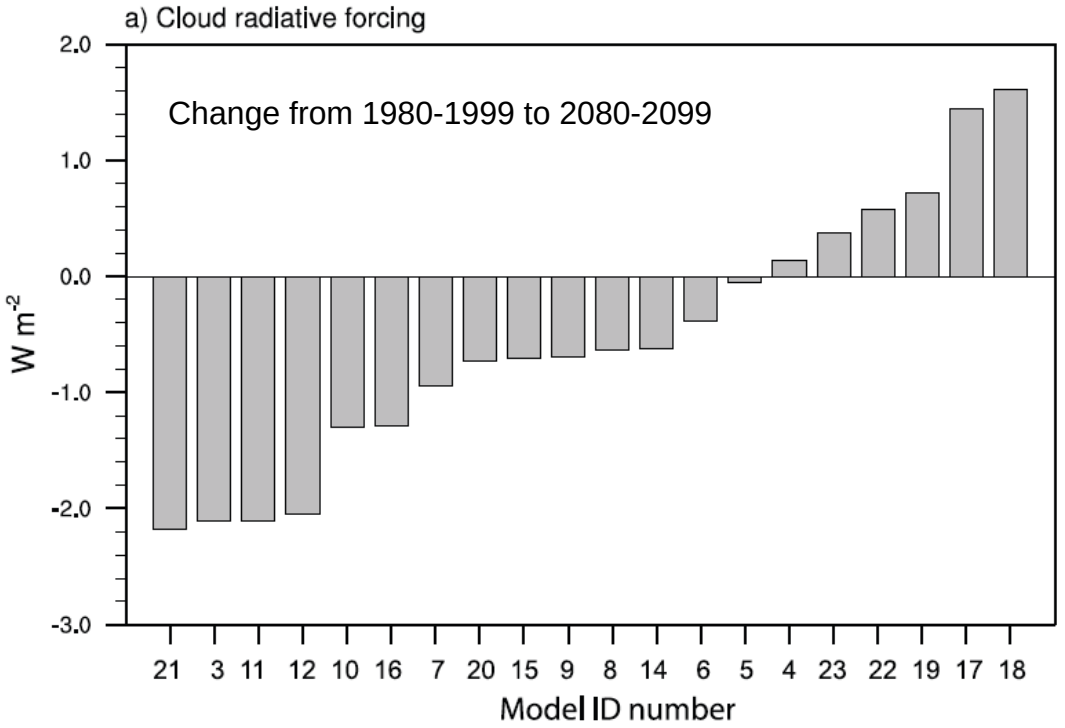


IPCC AR4, 2007

- Models do not agree on sign of cloud changes over much of globe.
- Models do agree on 3 to 4% decrease in upper tropospheric clouds.

Uncertain cloud radiative response

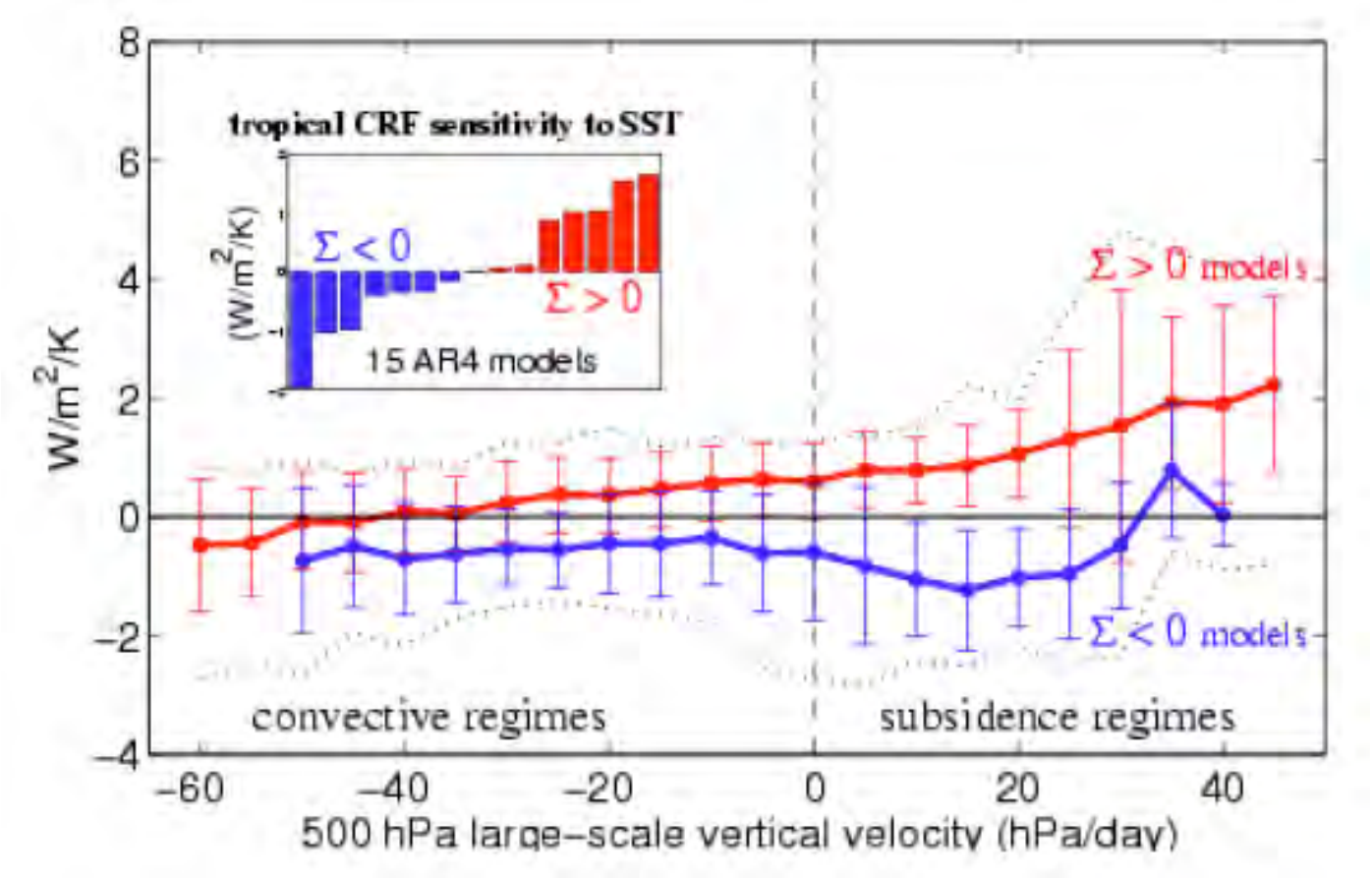
Change in cloud radiative effects in 21st century: A1B Scenario



- Models do not converge on sign of change in cloud radiative effects.
- Trends in cloud radiative effects have magnitude < 0.2 Wm^{-2} $decade^{-1}$.

Low confidence in cloud feedbacks

Change in cloud radiative effects: 1% CO_2/year simulations



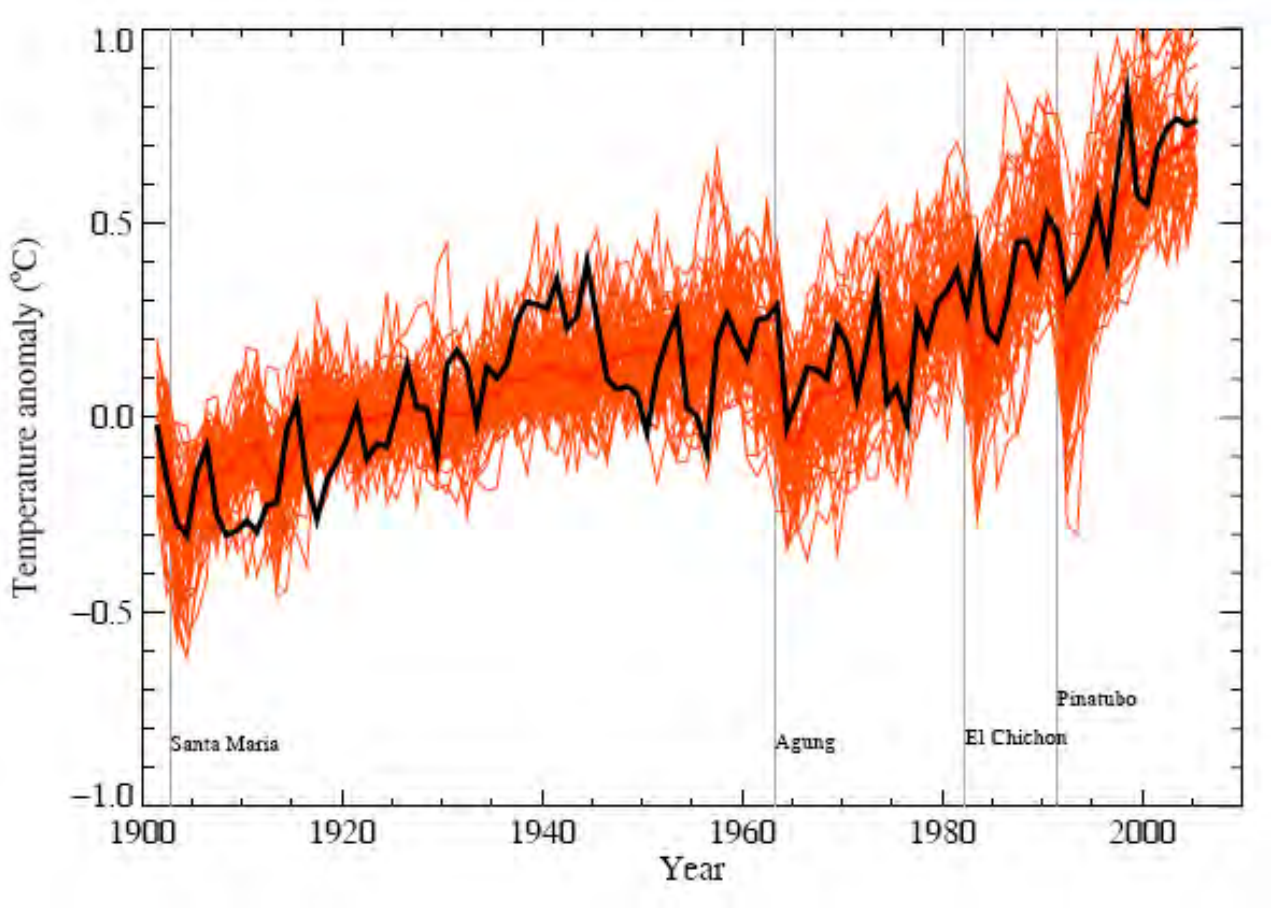
IPCC AR4, 2007

CLARREO and future climate change

- **Warming over next 30 years should be significant.**
- **Warming of upper atmosphere is a robust prediction.**
- **Warming over next 30 years may not help determine the most realistic models or emissions trajectories.**
- **However, information on sign of cloud feedbacks could discriminate O(50%) more realistic models.**
- **Will predicted trends in high clouds be validated?**

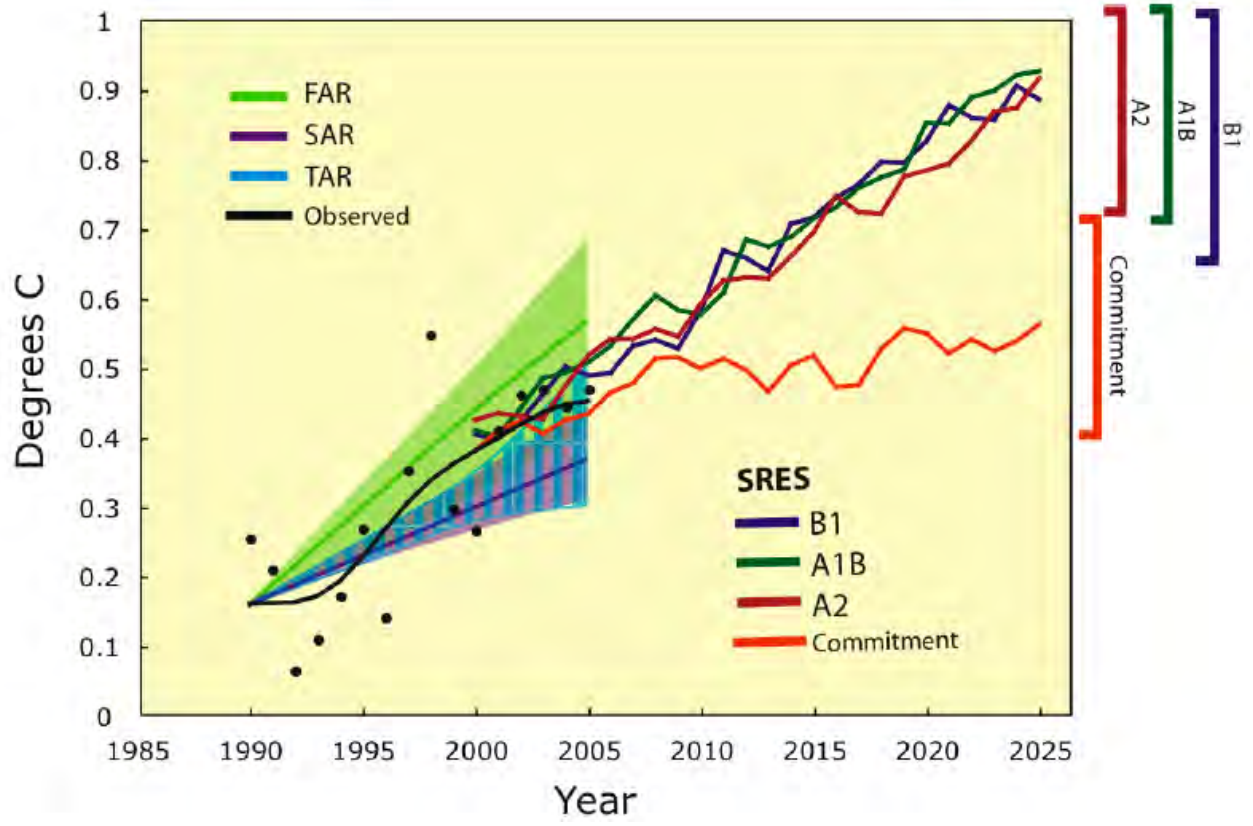
Confrontation of models with data

Global mean near-surface air temperature for the 20th C.



Veracity of near-term predictions

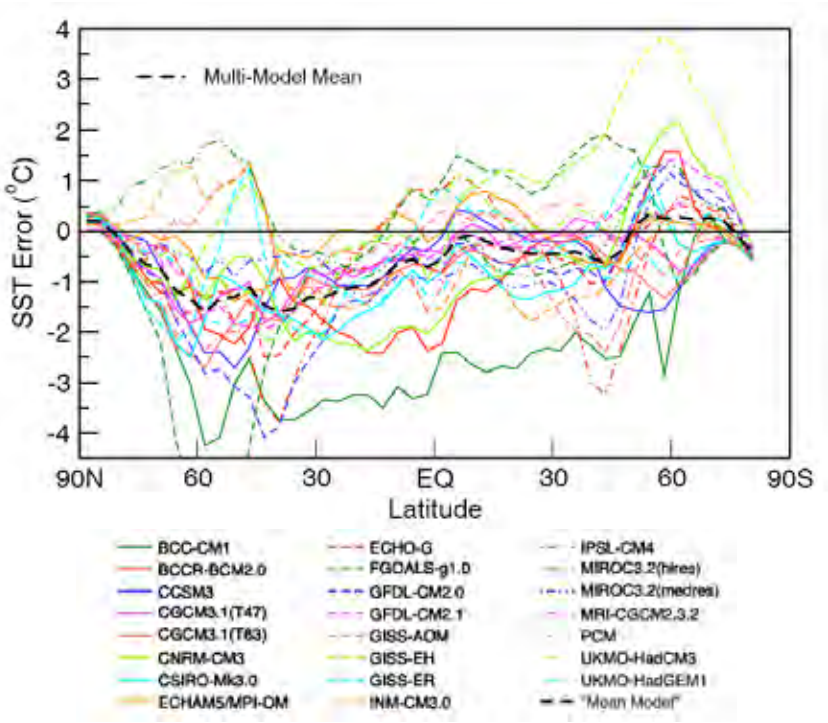
Modeled and predicted temperature anomalies from 1961-1990



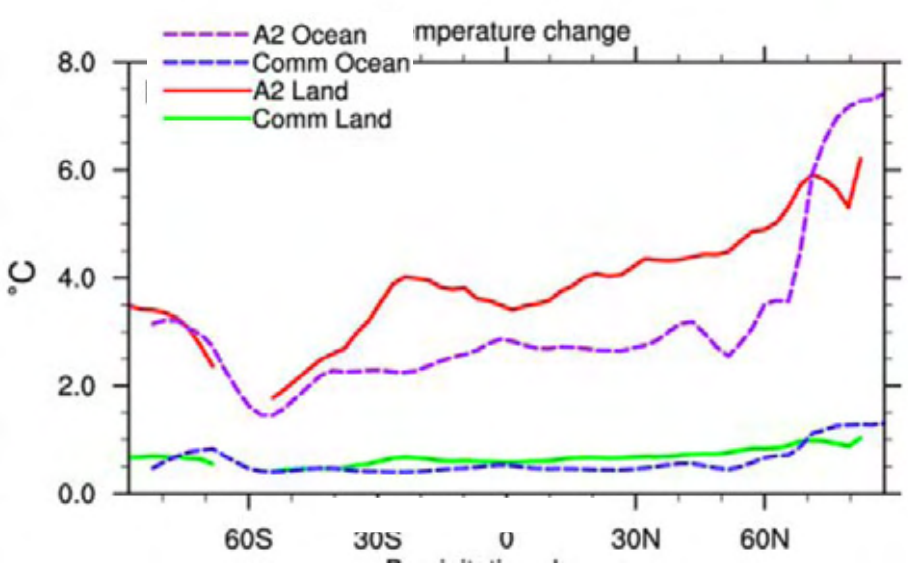
- Predicted rate since start of IPCC is 0.15 to 0.3 K decade^{-1}.
- Observed rate of increase is 0.2 K decade^{-1}.

Evaluation of climate models

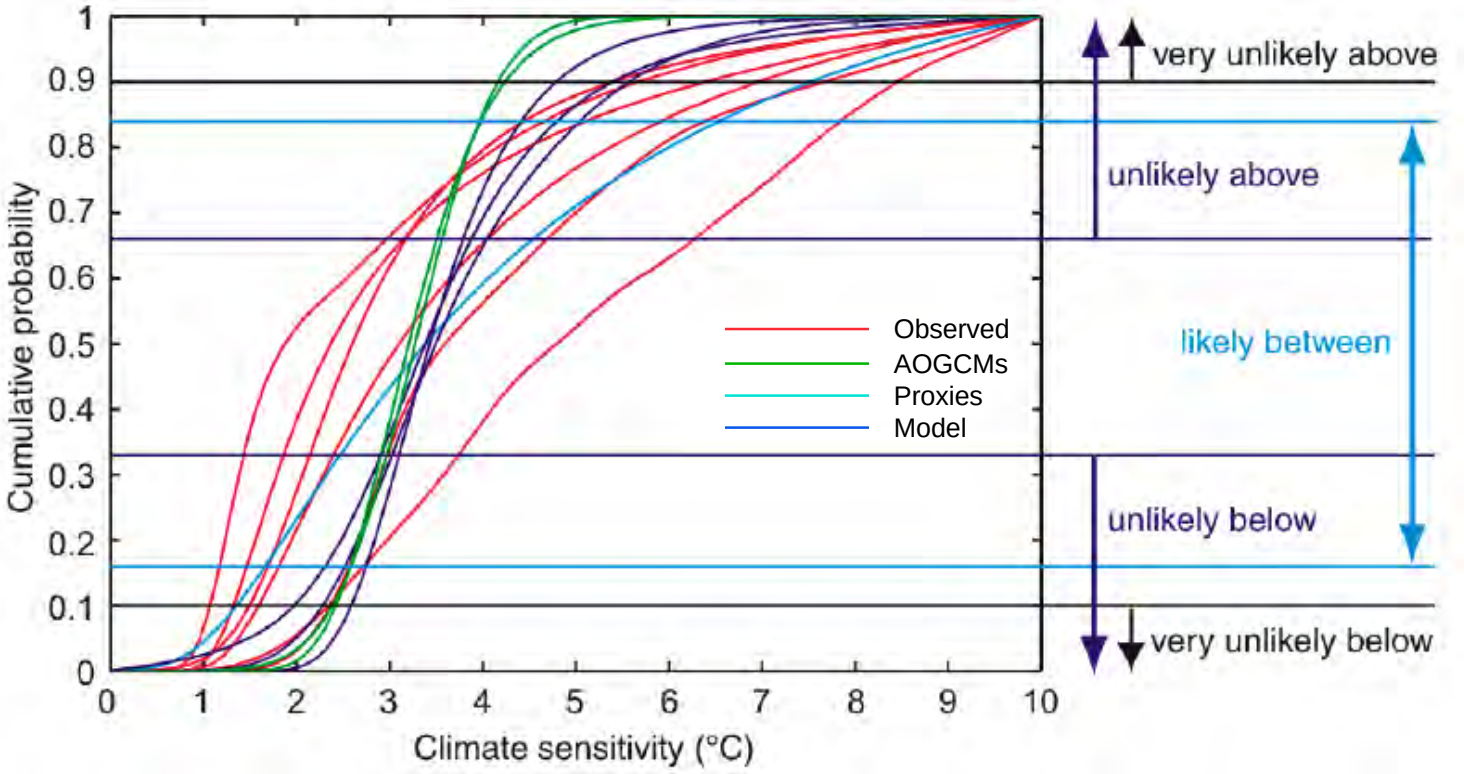
Modeled SST, 1980-1999



SST Change, 2080-2099



Distribution of climate sensitivity



- Equilibrium climate sensitivity is likely between 2 to 4.5K.
- Most likely value of equilibrium climate sensitivity is about 3K.
- Very high values (> 6K) cannot be excluded.

Issues for testing climate models

- **What tests are necessary and sufficient for accurate predictions?**
- **How are observables and sensitivity fundamentally related?**
- **We need empirical estimates of sensitivity that are robust to uncertainties in historical forcing.**
- **Fluctuation-dissipation theory links sensitivity to 2nd-order statistics (lagged correlations) of observables.**
- **This theory is not utilized in current assessments.**
- **Observational and model capabilities should be designed with tests of this theory as a top priority.**

Suggestions for near-term research

- **Perturbed physics ensembles are useful frameworks for linking observables and climate sensitivity.**
- **Existing ensembles provide traditional climate diagnostics.**
- **Range of sensitivity is weakly constrained using traditional climate diagnostics.**
- **It would be very useful to build a new ensemble designed for:**
  - **Emulation of CLARREO instrumentation**
  - **New diagnostics enabled by CLARREO instrumentation**
  - **Comprehensive tests of the connection between short-term correlations and climate sensitivity.**